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THE LAKSHMI PLATEAU STRUCTURE AS AN INDICATOR OF
ASTHENOSPHERE HORIZONTAL FLOWS ON VENUS

A.A. Pronin

Translation of "Stroyeniye plato lakshmi kak svidetel'stvo
gorizontal'nykh astenosfernykh potokov na venere",
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16. Abstract The structure of Lakshmi Planum in the western part of Ishtar Terra in a fold-fault setting which con- forms to the basic massif of the plateau with eruptive centers is constructed concentrically and it is interpreted from the point of view of the subsurface flow of materials in the form of horizontally diverging asthenospheric flows and gravitational creep. The surrounding structures are formed by the deformation of the more rigid lithosphere as it breaks away from the asthenospheric flow.		
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THE LAKSHMI PLATEAU STRUCTURE AS AN INDICATOR OF
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Introduction

The Lakshmi structure described below occupies the western part /26* of Ishtar Terra and is comprised of Lakshmi Planum itself - which is isometric relative to the plain region with altitudes of approximately 3.0 km above the level of the plain - and its surroundings. As the surrounding area we include Vesta Rupes in the south and southwest, the region with chaotic relief adjacent to it in the south and the massifs of Akna and Freyja Montes in the northwest and north. The periphery of the area surrounding Lakshmi on the north is comprised of an enormous wall approximately 1500 km long which separates Ishtar Terra from the northern plain. Below we will describe the Planum and its setting and present interpretations of the mechanism by which the structure formed as well as several conclusions.

Lakshmi Planum

Lakshmi Planum is a broad plain between 58 and 75° n.l. and 310 and 360° e.l. which is surrounded on all sides by a band of mountains. The major part of Lakshmi Planum is in the form of an irregular hexagon with flattened angles approximately 1400 km in diameter with a trapezoidal shelf in the north and a shelf in the east to the foot of Maxwell Montes; this is 800 km long and 200-300 km wide. The flat surface of the Planum is 3-3.5 km above its surroundings (a sphere of radius 6051 km described from the center of mass of the planet) and it is comprised of several small structures. We include first of all the Collette depression in the center of the western half of the

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Planum, which is in the form of an oval 130×180 km stretched in the meridional direction. The depression is approximately 2 km deep, it has a flat or slightly convex floor and terraced interior slopes (possibly deposition cracks). In the south on the surface of the depression floor, two flattened domes approximately 15 km across are visible. In the center of the floor there is a radar-dark area which is evidently smooth or covered with loose surface material. In the southeast of the oval of the depression in a 50 km area there is a system of ridges and wrinkles which are concentric with the Collette structure (fig. 1, 2).

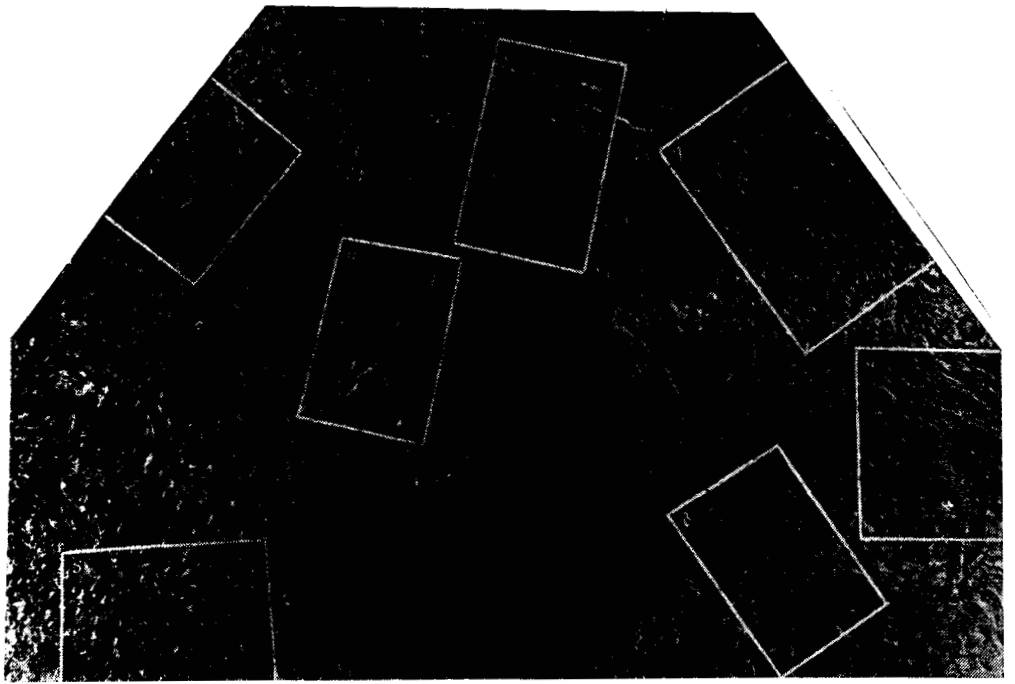


Fig. 1. A photographic map of Lakshmi Planum, and adjacent areas. The fragments shown in fig. 3-9 are outlined.

In the area around Collette at distances up to 250 km we can trace narrow bands and festooned regions which are lighter on radar than are surfaces which are similar to flows of liquid lava. As a rule, they

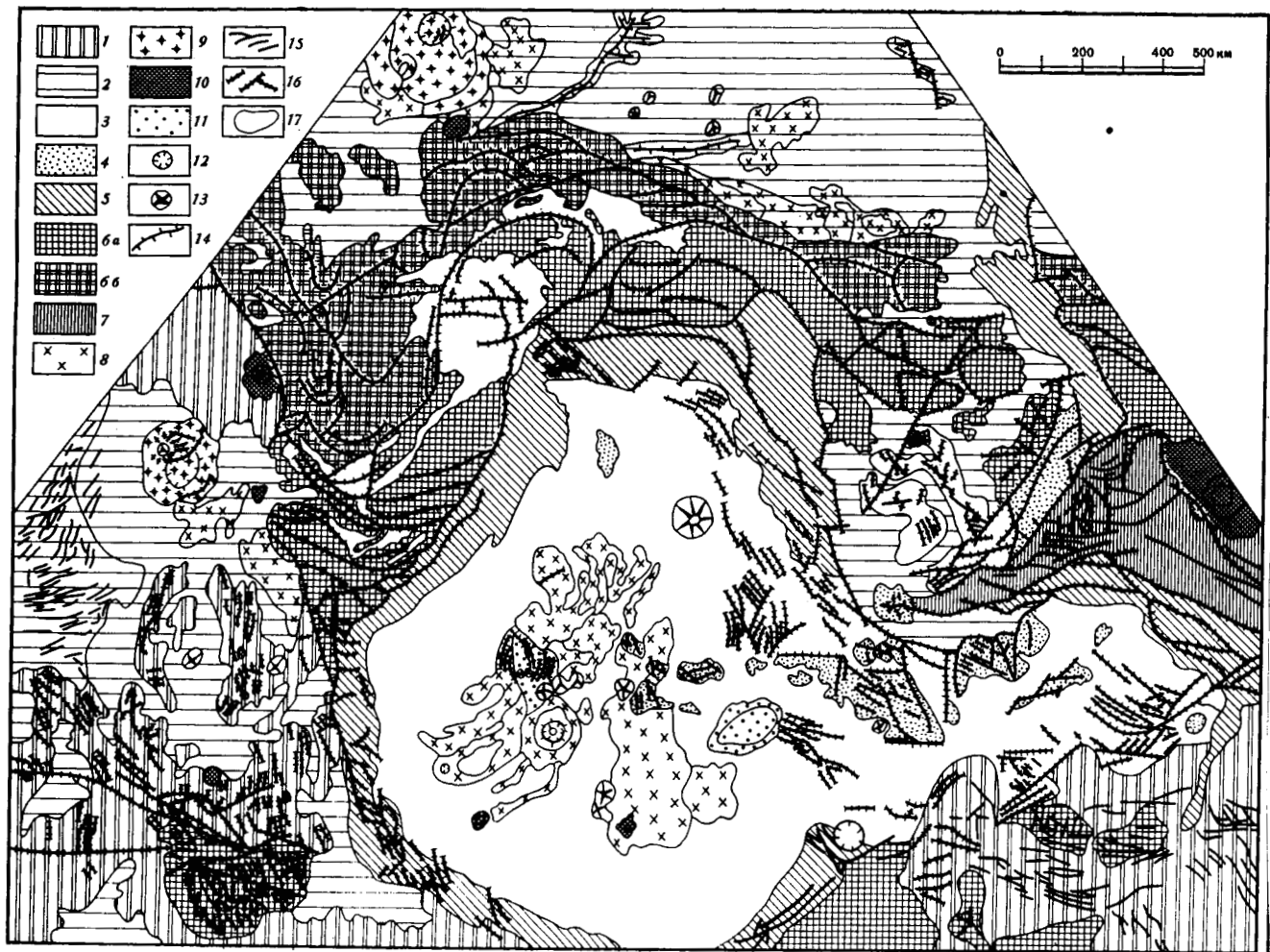


Fig. 2. The geological-morphological map of Lakshmi Planum and adjacent areas.

1-complex of rolling plains, 2-complex of relatively young plains and lava flows, 3-complex of rocks characteristic of Lakshmi Planum, 4-outliers of this relief inside Lakshmi Planum, 5-complex of the interior frame of Lakshmi Planum, 6-complex of the exterior frame of Lakshmi Planum, 7-massif of Maxwell Montes, 8-individual lava flows with visible boundaries, 9-ovoids, 10-impact craters with blankets of ejecta, 11-calderas, 12-round depressions of unclear origin, 13-dome, 14-axial lines of walls, 15-lineaments on the surface of the plains expressed in albedo, 16-lines of disturbances (break in continuity or shifting of a structure), 17-boundaries

are oriented radially with respect to the depression and cease to be visible in the image only close to the area to the west of Lakshmi. On the whole, the Collette depression with the system of diverging flows

is a gigantic shield volcano approximately 600 km across which is slightly stretched in the meridional direction and which occupies almost the entire western half of Lakshmi Planum.

In the center of the eastern half of Lakshmi Planum there is one other oval depression - Sacajawea - which is 200×120 km in area and approximately 1.5 km deep; its long axis is oriented in the northeastern direction. In the image it is less pronounced than Collette; we cannot see details of the structure of the interior slopes. Only two concentric light ovals and a horseshoe-shaped dark spot in the center indicate the existence of the depression. On the southeastern edge of the depression there is a series of escarpments which extend toward the southeast. They are visible in the form of narrow bright and dark lines at the limit of resolution and they form a system of flat-bottomed canals 3-10 km wide; these are similar to the surface manifestations of connected grabens and uplifts. /27

To the north of the Sacajawea depression, through the entire eastern half of Lakshmi Planum, a band of flat-topped plateaus which rise on average 500 m above the plain of the Planum extends in the latitudinal direction. The character of the relation of the plain material of the Planum with the plateaus along the rugged boundaries allows us to consider these plateaus to be outliers. Their rugged surface with a network of practically orthogonal ridges and wrinkles evidently bears traces of earlier deformations by which younger plain deposits in Lakshmi Planum were not affected; a small (100×50 km) isolated outlier similar to the one described is due north of the basic massif of the Planum.

The Southern and Western Areas around Lakshmi

In the south, the basic massif of the Planum is framed by a narrow band of mountains approximately 100 km wide; these mountains consist of linear ranges and basins between them and they are oriented almost everywhere along the edge of the Planum. The edge itself

forms an obtuse angle of approximately 120° with its vertex toward the south. Individual ranges inside the band extend for tens of kilometers (up to 100 km) in length and are 10-15 km wide. Near the southern extreme of the Planum where its edge changes from a north-northwest to a northeast direction, in a narrow band around it, two systems of parallel frames of ridges coexist and intersect at an angle of approximately 60° . /29

In the relief, an escarpment 3-5 km high (Vesta Rupes) corresponds to the band of linear ranges, so that the regional slope on the escarpment may reach several degrees. In the south the foot of the escarpment is bounded by an area with chaotic relief, while in places, for example in the west, the foot of the escarpment overlaps the chaotic relief and buries it. The area of chaotic relief which is adjacent to the southeastern setting extends in a short band 400 km wide and 1000 km long in the northeastern direction. The rugged relief of this region consists of chaotically oriented low ranges and plateaus with characteristic sizes in the tens of kilometers. A separate section of chaotic relief (150×250 km) is adjacent to the southeastern segment of the zone of linear ranges and basins (see fig. 1, 2).

The western segment of the area around Lakshmi appears to be different. Here the Planum is bounded by a sloped wall in the meridional direction, the surface of which is comprised of a plateau approximately 100 km in diameter and a series of arc-shaped ranges further to the west. This wall also forms an angle of approximately 120° with the southwestern segment of the setting. On the surface of the wall we can see several steep-sloped clefts which are probably gaping stress cracks. The largest of these begins in the southwestern corner of the surrounding area and extends approximately 150 km to the northeast at a width of several kilometers. /30

400 km to the west of this segment of the surrounding area there is an unusual structure in the form of a disk, bounded on the south-

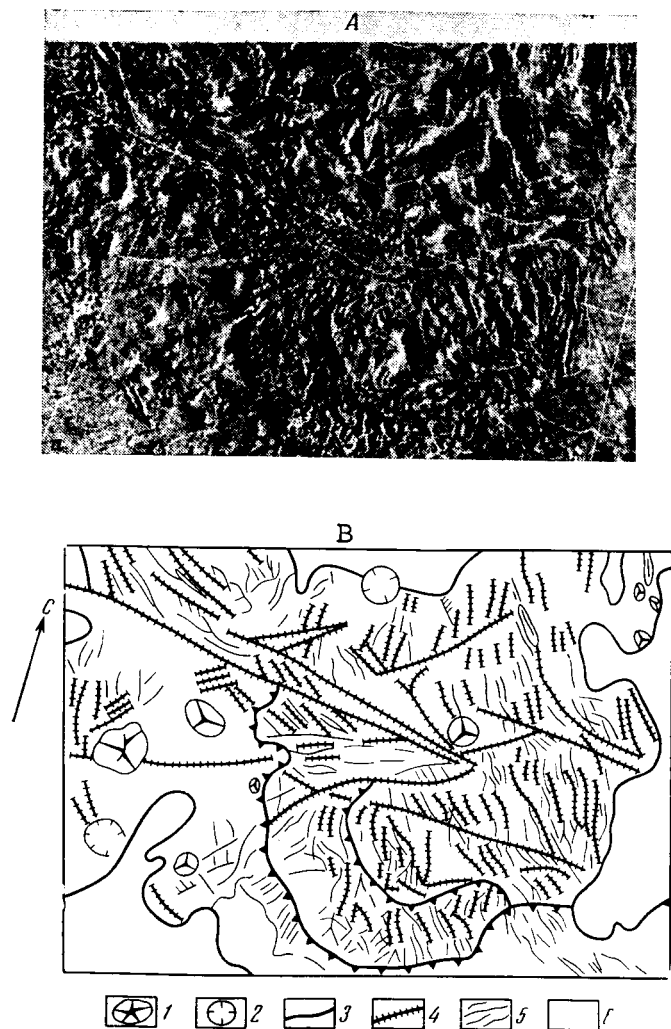


Fig. 3. A- a radar image of a section 400×600 km in size in the area to the southwest of Lakshmi, in the center of which there is a disk-shaped structure which is interpreted as the result of asthenospheric material coming to the surface. B- the scheme for deciphering the section: 1-dome, probably of volcanic origin, 2-impact craters, 3-boundaries, 4-breaks with shifts in structures and gaping cracks, 5-courses of the structures, 6-relatively smooth surfaces, probably of young lava flows

west by an escarpment superimposed on the surface of the southern plain, of a diameter on the order of 300 km. Along its edges the disk recalls the chaotic relief of the exterior frame of Lakshmi and in the center it is split by several clefts running northeast; these are tens of kilometers long and several kilometers wide. Further to the northeast, the surface of the disk goes into the hill relief area of the western area around Lakshmi, where we also see coulisse systems of arc-shaped clefts running northwest; these are similar to fault cracks. According to hypsometry, the surface of the disk rises 500 m above the southern plain (fig. 3).

Akna Montes

The northwestern boundary of Lakshmi Planum extends in a gentle arc approximately 700 km long to the northeast and it abuts the western surrounding at an angle on the order of 120°. At the same time it is the southeastern

foot of Akna Montes which rise 2.5 km above the surface of the

Planum. In the highest part, the massif of Akna Montes is comprised of a sequence of asymmetric ranges and basins up to 300 km long and up to 50 km wide with short steep slopes turned toward the Planum and long gentle reverses. On the map these are coulisse-like cuestas which are comprised of similar structures of higher orders. Toward the northwest the characteristic dimensions of the structures decrease along with the altitude of the Montes. The maximum length of an individual range does not exceed 100 km here. The boundary of the region with a relatively disordered structure has the form of a steep arc turned convexly toward the center of Lakshmi. Inside this region, several similar arc-shaped boundaries of higher orders are isolated (fig. 4).

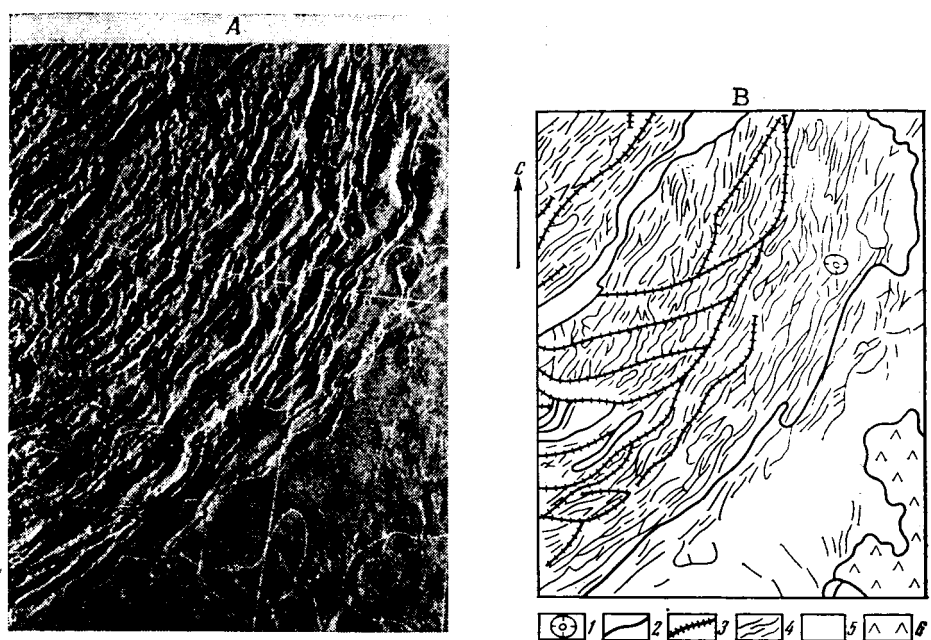


Fig. 4. A-radar image of a section 400×600 km in area in the northwest interior frame of Lakshmi (Akna Montes) and its highest part. In the southeastern part of the section a complex of the youngest lava flows develops and individual flows are visible inside this. B-Scheme for deciphering the section: 1-impact crater, 2-geological boundaries, 3-breaks, 4-courses of the structures, 5-relatively smooth surfaces, probably of young lava flows, 6-the youngest flows inside of which individual flows are visible.

The southwestern foot of the massif is a region of chaotic relief which recalls the southern frame of Lakshmi. To the southwest this region is bounded by a canal approximately 250 km long and up to 30 km wide; the surface of an extensive flow abuts this on the west. In some places the western foot of Akna Montes is inundated by material from the plain. In the north the boundary of inundation is a straight line and it is oriented to the northeast.

Northwest from the foot of Akna Montes the absolute altitudes decrease gradually from 2.0 to -0.5 km and the mountainous country here extends to the boundary with the northern plain. To the east this country is bounded by the "bay" of Lakshmi Planum which is separated from the main part by the converging massifs of Akna and Freyja Montes. The eastern part of this mountainous country is a system of short (up to 100 km long) asymmetrical ranges arranged in coulisse formation; their eastern extremes are covered by plain material from the "bay" of Lakshmi Planum.

In the western part of the mountainous country, the courses of the ranges change to northwesterly and in some places to meridional. The largest structure here in the northwest course is represented by two coulisse-abutting ranges approximately 500 km long in total, with the southern one being branched into two spurs. The overall course of this range coincides with the gigantic linear structures in the plain region with ovoids to the northwest of the country described here. It is possible that its western part bears traces of the mutual deposition of two structures - the area surrounding Lakshmi Planum and linear structures in the northeast (fig. 5). /31

Freyja Montes

In the north the basic massif of Lakshmi Planum has a trapezoidal shelf with which the mass of Freyja Montes abuts from the northeast. In the highest section the massif consists of a system of linear ranges up to 200 km long and 5-15 km wide which are oriented

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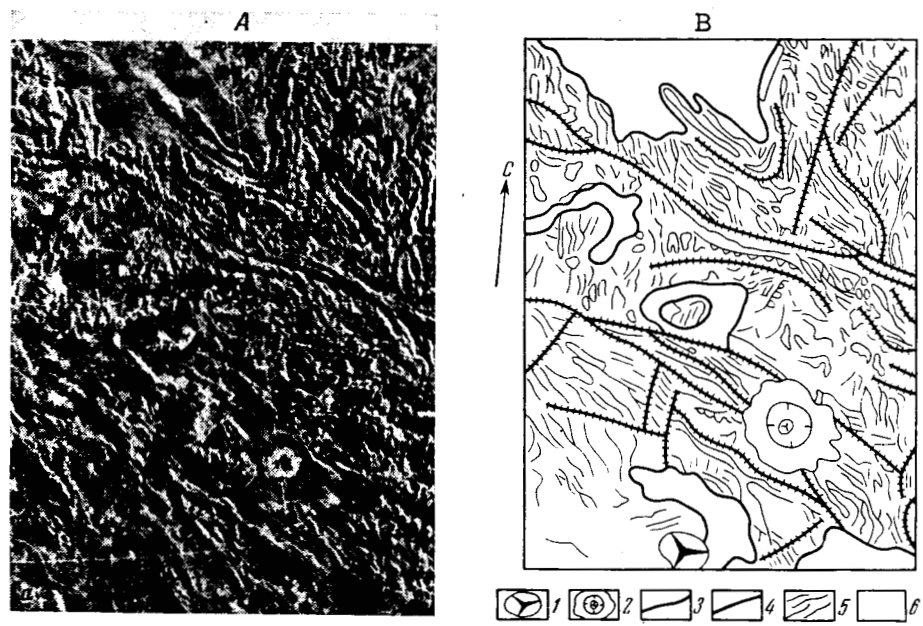


Fig. 5. A-radar image of a section 400×600 km in area in the northwestern part of the exterior frame of Lakshmi. The courses of ranges in intersecting directions indicate a shift in the structural dislocation. On the right toward the bottom an impact crater approximately 60 km in diameter with clearly expressed ejecta is superimposed on the complex relief. B-the scheme for deciphering the section: 1-dome, 2-impact crater with ejecta and a central ridge, 3-boundaries, 4-breaks, 5-courses of the structures, 6-relatively smooth surfaces, probably of young lava flows

in the sublatitudinal direction. The ranges have asymmetrical slopes - the northern ones are more positive than the southern ones in those cases in which it is possible to determine them. Sometimes the system of parallel ranges is shifted to low amplitudes in single kilometers along breaks in the northeasterly course. This ordered system of parallel ranges was followed in a sublatitudinal band 150 km wide and 400 km long. In the east the band bends to the south at an angle of 90-120°. On the adjacent surface of Lakshmi Planum we see radar-bright bands several kilometers wide which are oriented parallel to the frames around Lakshmi. Where the frames bend to the south, these bright bands form a lattice with rhombic units.

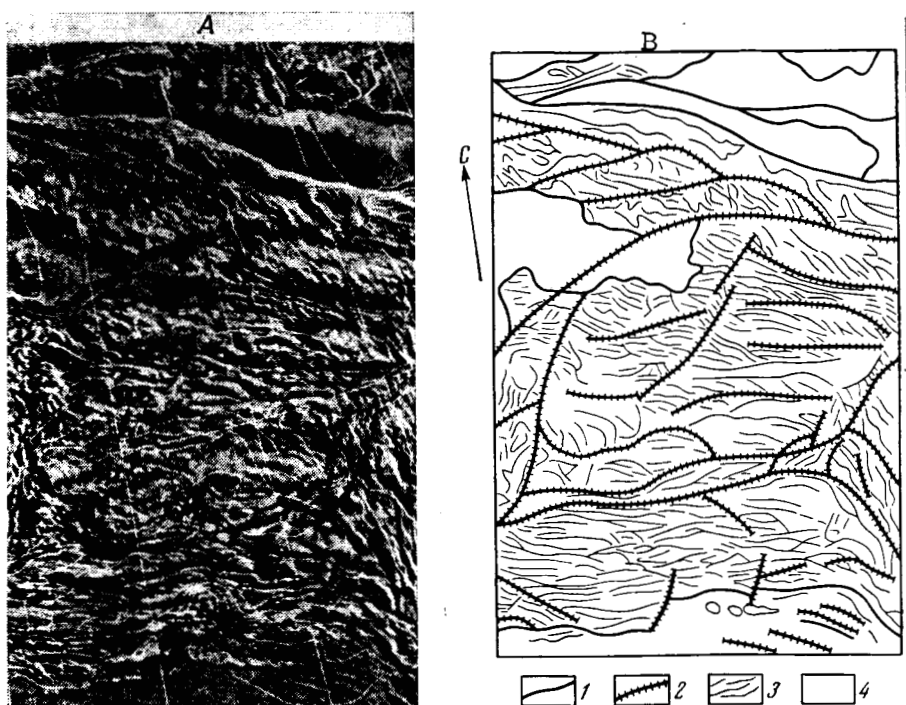


Fig. 6. A-radar image of a section 400×700 km in area in the northern part of the area surrounding Lakshmi (Freyja Montes). The system of sublatitudinal ranges in the south is replaced by a more disordered relief in the north. The wall of the exterior frame is bounded by the surface of the northern plain. B-the scheme for deciphering the section: 1-boundaries, 2-breaks, 3-courses of the structures, 4-relatively smooth surfaces, probably of young lava flows

The highest sections of the massif rise 2.5-3.0 km above the surface of the Planum (fig. 6).

The northern mountainous country is characterized by less ordered relief. In its eastern part, sublatitudinal courses of individual ranges predominate, but they are relatively ordered only inside blocks which recall in their form a roll of dimensions 200×100 km. The rolls are also oriented sublatitudinally and are separated by breaks which are seen along the lines of shift of the structures and canals. In the western part of the mountainous country the orientation of the ranges is more chaotic, but

submeridional courses predominate. Here, as a rule, the ranges are asymmetric and have steep eastern slopes. Further to the north, the courses of the ranges change to northwesterly and westerly, forming arcs which are turned convexly to the northeast. The boundary between the western and eastern parts of the northern foot of Freyja Montes corresponds to the courses of these arcs. To the west, a bay with a plain surface, complicated by arc-shaped escarpments with submeridional course which are turned toward the east, which plain is separated from the basic massif of Lakshmi Planum, abuts Freyja Montes.

To the north, a latitudinally oriented lowland with a relatively smooth surface abuts Freyja Montes. This lowland is bounded by a steep escarpment of a gigantic wall which extends 1500 km and which frames the entire Lakshmi structure on the north.

The Northeastern Basin

North of Freyja Montes in general the continuous frame of Lakshmi Planum is interrupted by a broad basin, the flat sections of the floor of which go into the northern plain. This is an isometric depression of diameter 600-700 km and the altitudes of the floor are 1.5-2.0 km above the surroundings. To the northwest, the wall-shaped structures of the exterior frame of Lakshmi with chaotic surface relief descend to the basin in a fan. They are submerged under the material of the plain, which covers them with meandering contact. The extreme parts of the wall-shaped structures are complicated by slides which are seen along arc-shaped separation niches and pressing walls (fig. 7).

In the southwest, the lowest part of the basin is a slightly stretched basin with a diameter of approximately 200 km. Its central part and eastern rim are slightly raised and they rise above the surface of the plain; the canal formed between them is filled with plain material. The raised sections of the floor of the basin are

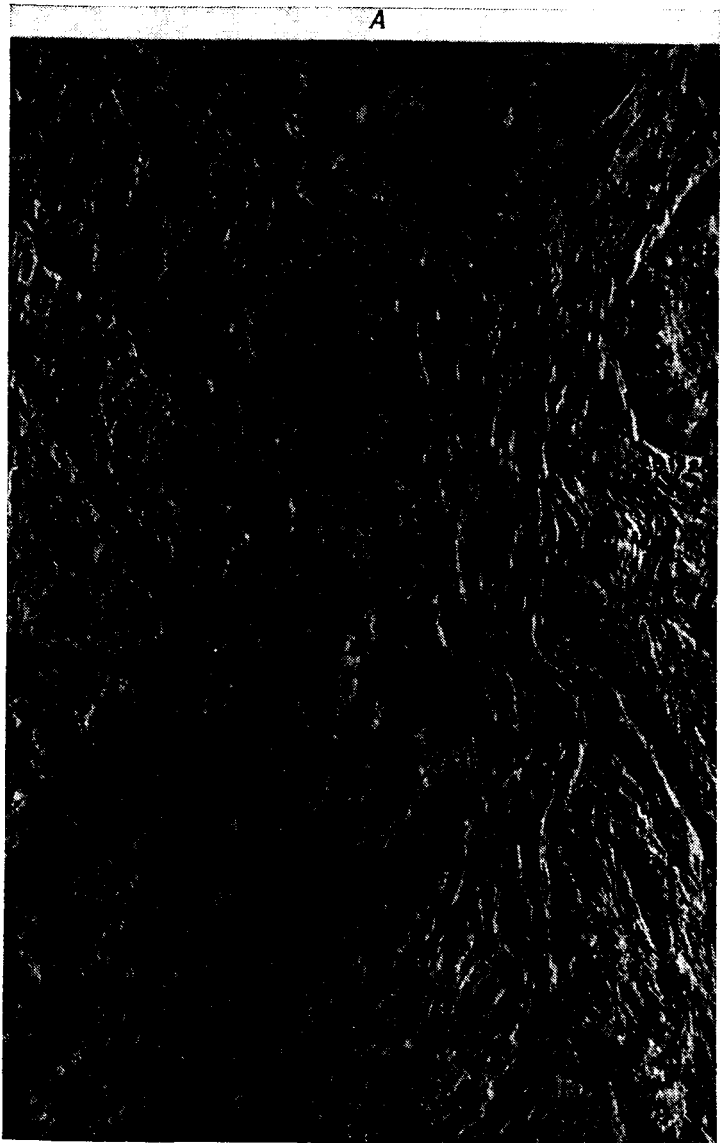


Fig. 7. A-radar image of a section 600x850 km in area north of the massif of Maxwell Montes. East of the meridional band of compression structures we can see a continuation of the broken northern frame of Lakshmi. In the center and the northwestern corner of the image we see slides at the end of the wall-shaped structures of Lakshmi's frame. B-schemes for deciphering the section: 1-boundaries, 2-breaks, 3-courses of the structures, 4-relatively smooth surfaces, probably of young

cleaved by wrinkles and clefts which are combined into systems which recall stress cracks. In the /33 southwest, along an escarpment more than 1 km high, the basin is bounded by the surface of Lakshmi Planum.

In the east the basin is framed by a band of linear structures 600-700 km long. The northern extreme of the band is submerged under the surface of the northern plain and the southern abuts the massif of Maxwell Montes. Wall-shaped structures with chaotic surface relief, which are similar to the structures of the exterior frame of Lakshmi, directly abut the eastern boundary of the band. Their T-shaped joints with the eastern boundary of the band indicate that the band is a cross structure. In the southwest the band is bounded by plain material from the floor of the basin.

In the southeastern part of the basin, where the



lava flows, 5-radar-dark sections
of "shaded" slopes, probably
large gaping cracks

km long and 50-60 km wide which is clamped between the two clefts. In the central part it consists of three oval massifs 50×60 km in area which are seen as "mega-rolls" of competent rocks submerged in a more plastic layered stratum. The similarity is emphasized by systems of narrow joined wrinkles and ridges (at the limit of resolution) which are oriented conformally with respect to the rolls and which recall flow lines. The floor of the basin is covered with

gentle rise to the northern foot of Maxwell Montes begins, above the surface of the plain a low part with chaotic slightly irregular relief rises (the characteristic size of the irregularities is from the limit of resolution to 10-15 km). Here we see several clefts which form a rare orthogonal lattice. Further to the southeast lies a narrow (20-40 km) ridge approximately 350 km long; it is bounded by two clefts and is oriented in a northeasterly direction. In turn the ridge consists of a series of smaller ridges which are arranged in a coulisse pattern and at an acute angle to its course. The large ridge is a natural boundary of the floor of the basin, since further to the southeast the rise to Maxwell Montes begins. The southeastern edge of the basin combines a crescent-shaped ridge approximately 400

plain-forming material with gently undulating relief and a smooth surface, in the northern part it is strewn with many domes several kilometers in diameter.

The Eastern Shelf of Lakshmi Planum

On the whole, the isometric platform of Lakshmi Planum at the latitude of the Sacajawea caldera has a shelf which extends 800 km to the north and is 200-300 km wide. Its eastern extreme abuts the foot of Maxwell Montes which rise in a steep escarpment above the plain of the Planum to more than 5.0 km. The surface of the Planum rises slightly to the east and while in the center of Lakshmi the altitude markers are 2.0-2.5 km, at the foot of Maxwell Montes they are 3.5-4.0 above the surrounding area (see fig. 1, 2).

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Within the shelf the surface of the Planum is smooth, above it, as in the center of Lakshmi, outliers of the massifs with rugged relief created by a network of straight wrinkles which intersect at angles from 45 to 80° rise up several hundreds of meters. The largest of these, 200 km east of the Sacajawea caldera, has an almost perfect rhombic form with a side of 200 km and a long diagonal oriented to the northwest.

In the southeastern corner of the shelf its surface is crossed by a series of parallel arc-shaped wrinkles with a general north-western course; their southeastern ends have a maximum width up to 10-15 km and they are gradually narrowed toward the northeast, ending in nothing. The wrinkles are from 50 to 200 km long and, judging from the "shadows", they have V-shaped cross sections without signs of walls along the sharp edges. Similar wrinkles, but less clearly expressed and smaller, are found along the entire southern edge of the shelf of the Planum (fig. 8).

The southern boundary of the shelf of the Planum recalls the rugged edge of a coastal shelf and the similarity is intensified by

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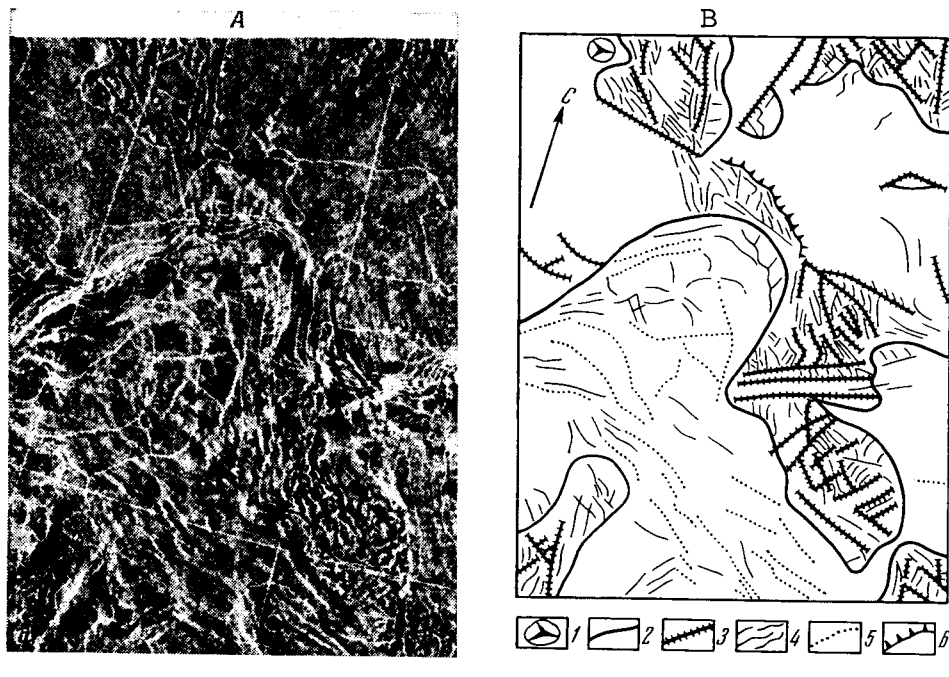


Fig. 8. A-radar image of a section 400×600 km in area on the southern boundary of the eastern shelf of Lakshmi Planum. The boundary between the smooth surface of the Planum in the north and the hilly plain in the south is marked by an escarpment 2.5 km high. B-scheme for deciphering the section: 1-dome, 2-boundaries, 3-breaks, 4-courses of the structures, 5-bright bands on the surface of the hilly plain, probably low escarpments, expressed as albedo, 6-expressed in the escarpment relief

the fact that it coincides with a shelf with a relief 2.5-3.0 km high which is turned toward the hilly plain, above the surface of which, at an altitude of 1.0-1.5 km, several irregular outliers of chaotic relief and isometric form rise up further to the south. The northern edge of the eastern shelf of the Planum is an escarpment turned toward the north; it is not expressed in hypsometry but is clearly visible in the images.

Maxwell Montes

According to the relief picture and hypsometry, the massif of Maxwell Montes has the form of a rectangle

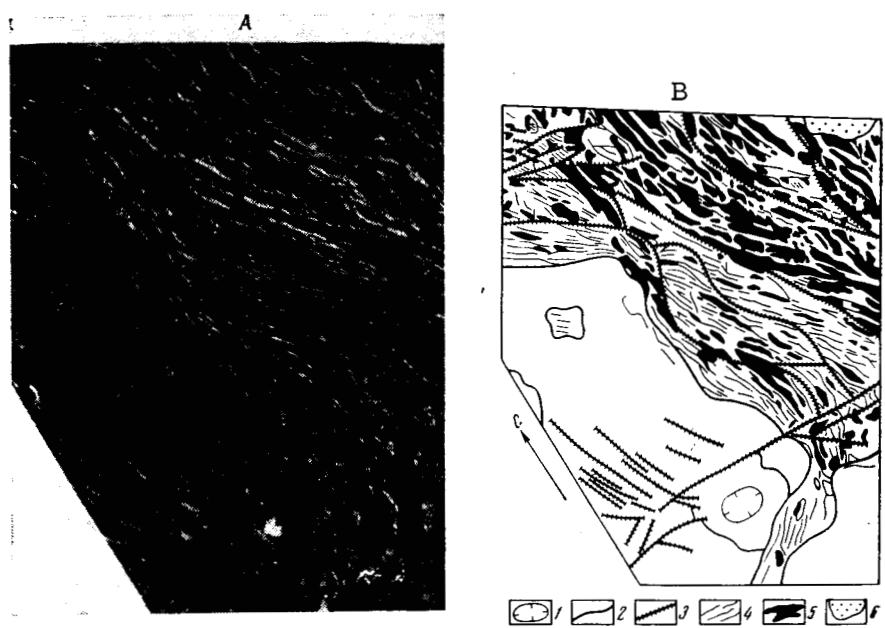


Fig. 9. A-radar image of a section 400×500 km in area at the site where the massif of Maxwell Montes joins Lakshmi Planum; the boundary is fixed by an abrupt shift from the plain of the Planum to a steep slope with banded structures which are parallel to the course of the slope. B-scheme for deciphering the section: 1-depression of unclear genesis, 2-boundaries, 3-breaks, 4-courses of the structures, 5-radar-dark "shaded" sections of the slopes, 6-ejecta from Cleopatra Patera, probably of impact origin

500×800 km in area which is oriented with its long side to the north-west and which has a stretched out western angle which is a spur separating the northeastern basin and the shelf of Lakshmi Planum. Within this area the massif is represented by its northwestern part, where several zones are isolated according to hypsometry and the relief picture (fig. 9).

The southwestern slope of the massif rises above the surface of Lakshmi Planum in a steep escarpment 5.0 km high. The entire slope is dissected subparallel to the foot by a system of connected ridges and wrinkles up to 5 km wide and 100 km long. By shifts in the banded structure, we may isolate several large lens-shaped blocks which are also oriented in a subparallel way to the foot. On

the surface of the Planum along the edge of the massif, a system of asymmetric ridges with steep western and gentle eastern slopes 5-10 km wide and up to 150 km long extends. These ridges are not expressed in hypsometry and the impression is created that it is precisely here that the surface layer of Lakshmi Planum begins to cleave into scale-shaped blocks with slopes to the east; these blocks are farther to the east than the densely "packed" ones on the western slope of the massif of Maxwell.

In the central part of the massif the relief picture changes abruptly; the boundary with the steep western slope is almost a straight line and it coincides with the line of disturbance of the structures. Long asymmetric ridges (up to 200 km) 20-25 km wide are characteristic of this part of the massif. It is as if these ridges consisted of sheets with slopes to the west, since their eastern "illuminated" slopes are as a rule narrower (<10 km) and their western slopes broader. On the whole, the picture of the slopes turned toward the radar recalls a system of lattices which is strongly stretched in the northwestern direction. This zone coincides with the region of the maximum altitudes of the massif, but in making a map with resolution 500 m, the vertex of the massif turns out to be almost completely flat (the slopes here are one order lower than on the western slope). The width of the zone is approximately 200 km, its length on the order of 400 km. /37

Further to the northeast the massif descends to the region of chaotic relief, where the altitudes are on average the same as on the eastern shelf of Lakshmi Planum. Approximately in the center the northeastern slope is complicated by a large (diameter 130 km with respect to the external wall) double-ring structure, the northern surface of which is smooth and which has increased roughness of the microrelief; this is evidently related to the presence on the surface of ejecta from the ring structure, similar to an impact crater. The relief of the remaining part of the northeastern slope is disordered: here we observe only short (20-30 km long) ridges and knolls,

arc-shaped lines of shift which recall the separation niches of slides, and only in some places is the parallel-banded ordered structure preserved. The eastern boundary of the massif with the region of the development of chaotic relief is marked by a series of arc-shaped lines of disturbance.

The disordered relief, elements of which are short ridges and knolls, also develops on the southern slope of the massif, with only this difference, that at the southeastern foot it is organized with some similarity to walls which are conformal to the outlines of the massif and which follow almost precisely the direction of the isohypse. The formation of these walls may be related to the creep of material downward along the slope and their relative clarity to the fact that the slope here is oriented along the courses of the structures in the central zone of the massif. In the south the foot of the massif is "inundated" by plain-forming material at an altitude of approximately 3.5 km. /38

On the northwestern slope of the massif, the central zone with a large relief picture along an irregular serrated boundary comes into contact with a section which differs sharply according to the picture of the structures, their orientation and surface roughness. The section stretches 400 km toward the northeast, its northwestern boundary is relatively straight and in the southeast there are two triangular shelves which go into the central zone of the massif. The wrinkles of the gentle "wrinkled" relief are intersected here by spots and lines with low reflecting capability; on the stereomodels they are seen as gaping clefts. The system of such clefts in the northwesterly course intersects the surface of the section in the west. The largest of these extends 100 km and is several kilometers wide. On the whole, the banded structures of the Maxwell massif do not go to the edges of the section, as if this were a cover with traces of stress deformations.

Discussion

The youngest formations in the described Lakshmi structure are evidently parts of the Planum itself formed by flows of liquid lava from at least two centers, the Collette and Sacajawea calderas. The large spread of Collette caldera in uniform amounts and the clearly traced boundaries of individual flows indicate its relative youth. The region of radial spread of the flows in relief corresponds to a gentle rise approximately 400 km in diameter and on the order of 500 m high. From under the surface of the lava flows there are outcrops of slightly raised sections with intersecting systems of cracks. Since the flow material in the form of "bays" goes into the clefts of the cracks in the outliers, the flows which comprise the Planum are formations which were superimposed on the outliers [2].

It is possible to determine the relief of the mountainous regions on the basis of stereomodels in places in which these make it possible to overlap individual bands during photography. The comparison of the stereomodel with altimetry data and with the known morphology of the impact craters confirms its adequacy. Significant parts of the massifs of Akna and Freyja Montes which turn out to be systems of asymmetric ridges with courses which conform to those of the Planum are in the zone of the stereoimage; this indicates their single genesis. Such systems of asymmetric subparallel ridges may arise either in block (plate) or folded structures. Independent of mechanism, the formation of such structures requires the presence of a relatively rigid surface layer on the order of 10 km thick [3] and conditions of horizontal compression. In the boundary regions we may see that plain material is used in the formation of the mountainous frame and that in the southern part of Lakshmi Planum the linear ridges of the frame are structures superimposed relative to the chaotic relief region. In the northwest and north (Akna and Freyja Montes) toward the periphery of Lakshmi the "degree of disorder" of the structure increases; this may also indicate indirectly the longer

history of the deformations and, consequently, an increase in age toward the periphery.

Irrespective of the type of structure (folded or block), the linear structures in the immediate environment of the Planum must have been formed by the forces of horizontal compression transverse to their course. The systems of mutually intersecting cracks in the southernmost part of the Lakshmi structure, the mechanism of formation of which has been described for Maxwell Montes [1], indicate this direction of forces. However, unlike Akna and Freyja Montes, the zone of linear ridges in the southern frame does not rise above the surface of the Planum. Nevertheless, the slopes on Vesta Rupes may attain several degrees. Considering the high temperature of the material in the surface layer, with such a regional slope the structures surrounding Lakshmi on the south may turn out to be pressure folds formed during the passive gravitational flow in the massif of the Planum [4]. Akna and Freyja Montes, which rise above the level of the Planum, were evidently formed by more active forces of horizontal compression; this caused their significant uplift. /39

If we look at the exterior frame of Lakshmi Planum the clear concentricity of the structure is complicated; this is caused evidently by the great age of this zone and is related to the more complex history of its formation.

In the southeast the region of chaotic relief is complicated by arc-shaped depressions turned convexly upward along the slope. On their exteriors they are similar to separation niches of gigantic (>100 km) slides which are accompanied by the deposition of crescent-shaped blocks and lava flows. Broad lava flows which spill over the surface of the smooth plain in the south begin in one of the semi-circular niches on the southern edge of the eastern shelf of Lakshmi Planum (see fig. 8). The disk-shaped structure in the southwest of the exterior frame of Lakshmi recalls the terminal part of the gigantic flow of plastic material which flows or is released from

beneath the edge of the Planum toward the southwest. Toward the Planum, the surface with flow structures gradually goes into an uneven relief with deposition cracks. Such a picture may arise during movement of a flow which encompasses the roof of the niche in which it begins. Similar separation niches also exist in the area surrounding Lakshmi to the west. The largest of them is seen as a gigantic cleft abutted on the west by a broad crack flow which covers an area of approximately 300×100 km.

The northeastern courses of structures in the massif of Akna Montes are preserved only in its eastern part. In the west they shift to northwesterly courses which coincide with the orientation of the linear structures in the region of hilly plains with ovoids in the west and they indicate a shift in the structural deformation plans (see fig. 5).

Freyja Montes and the mountainous country to the north are on the whole a single massif with sublatitudinal courses; this massif abuts the wall of the exterior frame of Lakshmi in the north. The massif may be seen to result from homogeneous compression deformation in the north-northeasterly direction.

The gigantic wall of the exterior frame of Lakshmi in the northeast extends northwest from 355° e.l. almost 1500 km and it changes to a southwesterly course only at the longitude of Lakshmi "bay". Inside the wall, individual ridges are oriented approximately parallel to the boundaries of the entire Lakshmi structure and along the exterior boundary the wall is a formation superimposed on the northern plain.

In the northeast the practically continuous frame of Lakshmi is broken by a basin, the floor of which abuts the northern plain. The continuation of the northern frame of the Planum here is crossed by a meridional band of linear structures and it is seen further to the east in the form of short wall-shaped structures which abut the band

from the east. The band itself, consisting of parallel ridges, may be interpreted as a compression structure in the latitudinal direction, however the basin which abuts it shows traces of stress, indicated by the fan of walls of Lakshmi's frame which descend to it and by the drop in the level of the floor. Thus, the basin itself may play the role of a rear depression with respect to the band of compression structures and its formation may have resulted from the subsurface outflow of material toward the center of Lakshmi.

On the southeastern edge of the basin the situation may be interpreted as a righthand shift in the northeasterly course. This is indicated by extensive canals which mark the "fitted in" lines of disturbance, by S-shaped ranges and compression walls ("mega-rolls") which join them at acute angles in the northwest and by gaping crack clefts in the southeast. The meridional band, which is abruptly intercepted in the south by this displacement, thus turns out to be a structural analog of the recent interior frame of Lakshmi which is shifted to the northeast along the displacement; this was a reason for the break in the exterior frame in the north. /40

A similar formation scheme is also suitable for explaining the structure of Maxwell massif, the western boundary of which with the shelf of the Planum marks an abrupt shift in the conditions of horizontal stress (the gaping cracks on the surfaces of the outliers and the Planum itself) due to compression (structures on the steep southwestern slope of the massif). The shelf of Lakshmi Planum, the surface of which, both according to the relief picture and hypsometry, is indistinguishable from the basic massif of the Planum, evidently does not randomly abut the foot of Maxwell Montes. If this mountain structure is seen as the structural analog of Akna and Freyja Montes, then its formation must be related to one more subsurface flow of material - the most powerful, judging from its length and the altitude of the mountain structure created by it.

An extensive latitudinal line of disturbance, which is also a

displacement, but with a lefthand shift, intercepts the eastern shelf of the Planum and the massif of Maxwell Montes from the south. Wrinkles to the north of it which are narrowed at one end and which are support fragments and compression walls from the south which abut the displacement at an acute angle indicate the presence of a displacement. Latitudinal displacements which bound the shelf of the Planum and the massif of Maxwell Montes evidently play the role of terrestrial transformed fractures which allow the flow of material in different areas to move at different velocities.

Based on the idea of flows of material which diverge radially from a single center, the formation of the fold-fault setting of Lakshmi may be seen as the result of the accumulation of surface layer material. This must have great rigidity relative to subsurface material, as follows from the existence of a vertical temperature gradient on Venus; there is no basis for denying this. However, this inevitably leads to the conclusion that separation of the plastic deep layer from the more rigid surface layer is essential and that the scale-shaped blocks of the latter warp and cleave. It is possible that at the junction of the eastern shelf of Lakshmi Planum with the massif of Maxwell Montes we observe traces of precisely this process.

In calculating the total dimensions of the Lakshmi structure and the dimensions of elements of its setting, it is appropriate to call the flows asthenospheric and the rigid surface layer the lithosphere of Venus. Thus, the structure of Lakshmi merits designation as a peculiar stress center which arises above an anabatic current of heated interior material (the so-called mantle diapir) (fig. 10).

Conclusions

1. Lakshmi Planum and its setting comprise a single structure formed by a single process; its compactness and the conformation of the surrounding area indicate this.

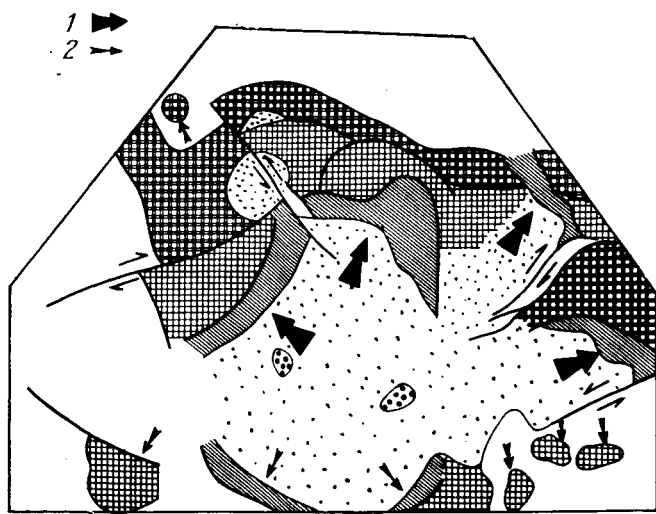


Fig. 10. Diagram of the tectonic structure of the region. It illustrates the direction of asthenospheric flows (large arrows) and gravitational flow of the massif of the Planum (small arrows)

2. At the basis of the mechanism of formation of the structure is the process of the ascent of material from the interior of the planet to the surface and its horizontal flow, which is accompanied by folding deformations and/or the formation of tectonic plates. This allows us to speak about Lakshmi as a peculiar center of radial spreading, however the spreading process ceased at the stage of accumulation of the lithosphere into massifs; this was accompanied by separation of the asthenospheric flow. During formation of the structure the lithospheric layer was approximately 10 km thick.

3. Large-scale horizontal shifts allow us to speak of Venus as a planet with a very complex tectonic life in comparison with primitive members of the terrestrial group (the moon, Mercury, Mars), where the tectonic style is limited to vertical motion. This provides a basis for considering Venus an intermediate link in the series of increasing complexity in types of deformation between the earth, with its tectonic plates, and Mars, the tectonic life of which stopped at the stage of

the formation of gigantic canyons and broad rises crowned by large shield volcanoes.

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